Complex effect of secondary salinization and composting on soil respiration

József ZSEMBELI[1] – Yuriko MORI[2] – Géza TUBA[1] – Krisztina CZELLÉR[1] – Györgyi KOVÁCS[1]

1: Karcag Research Institute RIEF University of Debrecen, H-5300 Karcag, Kisújszállási út 166. zsembeli@agr.unideb.hu

2: Faculty of Agricultural- and Food Sciences and Environmental Management, H-4032 Debrecen, Böszörményi út 166. yuriko.mr@gmail.com

Abstract: Salt-affection has been and still is a critical issue facing croplands in a large portion of the Great Hungarian Plain. Compost is known to have a positive effect on salt-affected soil, but little is known about the correlation between soil organic matter and bacterial activity. Microbial biomass and activity is found to be relative to levels of soil organic matter (SOM). Bacterial activity is affected by both salts and organic matter, and this research aims to determine the breakpoint and relationship between those two parameters. A pot experiment with 27 pots was set in Karcag Research Institute of RISF UD where soil respiration was measured under controlled conditions over a 16-week-long period. During the initial phase of the experiment, compost was added to non-salt-affected soil in differing doses (0, 25, 50 t/ha), and each sample was irrigated with a solution of different salt concentrations (0, 600, 1800 mg/l) with three test replications. At the tenth week, the compost was added to each at second time. At the thirteenth week, soil conditioner, rich in N, S and Ca, was added equally to each soil sample. Following the experimental phase, nutrients and bacterial colony measurements were conducted. During the phase of the experiment with compost application alone, the results demonstrated that salt concentration of irrigation water and compost ratio had negligible influence on soil respiration. However, following the addition of soil conditioner, a dramatic increase in respiration was recorded with initial spike of chemical reaction and second spike with biological reaction. Nutrient components were highly affected by salt and SOM, therefore, soil microbial activity fluctuates with variable reasons including combination of nutrients under salt stress environment.

Keywords: CO_2 emission, composting, soil organic matter, secondary salinization

Introduction

Salt-affected soils are often found in arid or semi-arid regions. 230 million hectares of land are available for irrigation, 45 million hectare (19.5%) are salt affected currently. Furthermore, increased salinization of arable lands may result in a 30% loss of land, with some estimates as high as 50% by 2050 (Wang et al., 2003). The problem is caused by excessive salts inhibiting plant mineral nutrients uptake which, in most cases, leads to prematurity and low crop yield. However, salt resistance in plants is a complex interaction of characteristics determined by a number of genes and gene combinations, and there have been limited successes in developing salt-resistant species (Ahmad and Rasool, 2014; Roy et al., 2014). In order to utilize the salt-affected soils, many studies have been conducted to improve the quality of soil physically, chemically and biologically through the implementation of organic wastes as fertilizers and amendments (Diacono and Montemurro, 2015; Tejada et al., 2006; Yadav and Agarwal, 1961).

However, it is still unknown whether plant and soil quality is affected negatively due to the direct salt pressure, or to the indirect effect of a decline in soil organic matter which has a positive effect on soil structure (Wong et al., 2010). The relationship between salinity and soil organic matter on a microbial community needs to be studied further in order to develop the fundamental understanding and resulting applications. The aim of our research is to investigate the effect of compost on salt-affected clay soil. Microbial biomass and activity is found to be relative to levels of soil organic matter (SOM). It is little known whether low microbial biomass is affected directly by salt accumulation or by reduced levels of SOM due to poor plant growth in salt-affected soils. Bacterial activity is affected by both salts and organic matter, and this research aims to determine the breakpoint and relationship between those two parameters.

Materials and methods

A pot experiment was conducted at the Karcag Research Institute RIEF University of Debrecen (KRI) in Karcag, Hungary where the wide range of soil is affected by salinization and sodification due to shallow and saline underground water with high clay contents. It is a representative place where secondary salinization has been observed, so this place was chosen for experiments with high applicability.

The experiment was conducted about 120 days. Parts of experiment design including duration, parameters of measurements, and compost rates were referred to Wong et al. (2009). This experiment investigated the correlation between compost and salt concentration on microbial activity. All treatments were replicated three times.

Soil samples were taken from the grounds of the Karcag Research Institute where underground water did not affect soils with soluble salts. Soils were carefully sieved through 5 cm mesh, and mixed well to provide uniform samples. Soil properties including soluble cations, pH, and humus contents were analyzed prior to field experiment. In this study "Terrasol," which is a mature compost mainly composed of sheep manure products released from KRI, was used. The doses of application were followed by the producer's recommendation.

In the region of Karcag, well water is rich in soluble salts, which leads to salinization and sodification. In this experiment, well water was used to simulate conditions similar to the real situation happening in this region. Well water contains approximately 1800 mg/L of soluble salts and is approximately pH 7.4 year-round with little fluctuations from the past experiments in the institute. Well water was used in this experiment because secondary salinization has been observed around this area with well-water irrigation (Zsembeli et al., 2011).

Each sample was irrigated after the soil became dry (roughly once in one to two weeks) to maintain humidity. Samples were irrigated and monitored for the microbial response to salt accumulation over time. Obviously accumulation of salts increased as time proceeded.

6kg of soil was placed in each 10 L bucket, and incorporated with different amounts of compost during the 1st week of the experiment. All the samples were irrigated after soil dried. Table 1 indicates the experimental design. During the tenth week, compost was added to each sample a second time, effectively doubling the compost/soil ratio. During the final stage, beginning in the thirteenth week, 4.1 g of soil conditioner as recommended by the producer was added equally to each sample (since the sample results were not significantly different at this point). The soil conditioner was a product called "*Solactive*" from Timac Agro. It is rich in nutrients; N 14%, SO_3 28%, CaO 22%, and MgO 2%. Hand

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tillage was performed after both compost and soil conditioner application to create a more uniform mixture.

The experiment was conducted in a room with moderate temperatures to avoid cold outside weather, and moved outside with overhead cover once the weather became warmer during June. Samples were irrigated 28 times in total amount of 2.6 litres.

Table 1. Design of the pot experiment

Organic Matter / Salt Concentration	Control (0 t/ha)	Compost (25 t/ha)	Compost (50 t/ha)
0 mg/L (control)	0-0	0-25	0-50
600 mg/L	600-0	600-25	600-50
1800 mg/L	1800-0	1800-25	1800-50

To measure soil respiration, CO_2 measurement was often used to monitor the microbial activity. CO_2 measurement was conducted on the day after irrigation to have same conditions of wetness since the water content of soils has correlation with microbial activities. CO_2 was measured with a Gasalert Micro 5 infrared gas analyser. The same methodology was used in KRI by Zsembeli (2006) previously.

Results and discussion

Our hypothesis was that microbial activity is influenced positively by compost and negatively by salt stress. In order to have some ideas about the correlation between those two parameters we determined the carbon dioxide emission (soil respiration referring to microbial activity) from the treated soils of the pot experiment.

Fig. 1-3 show the results of soils respiration of the soil samples with the same salt/water concentration levels for each compost/soil ratio over the four-month-long duration of the experiment. The results show that application of compost twice did not show significant differences in soil respiration. However, after the application of soil conditioner which is rich in N, S, and Ca, there were significant differences between different irrigation salt concentrations at 98th day ($P < 3.3e-17$). The samples irrigated with 1800 mg/L water had the highest soil respiration, and the lowest respiration level for deionised water. However, after the initial spike, salt concentration was found to have no significant effect on soil respiration when measured at 113th day ($P = 0.59$).

Overall, our data indicate that irrigation did not affect soil respiration with compost application alone. However, high compost ratios slightly improved soil respiration at all levels of salt concentration. Application of soil conditioner after compost triggered the two spikes in soil respiration, and the interaction between salt and compost can be seen (98th day: $P < 0.026$, 113th day: $P < 0.030$).

First spike was occurred with different salt levels. To amend saline soils, $CaCO_3$ (limestone) is usually applied to neutralize exchangeable Al or Na, and supplies Ca in acid soils. Ca precipitates as calcite ($CaCO_3$) instead of reaching with infiltration.

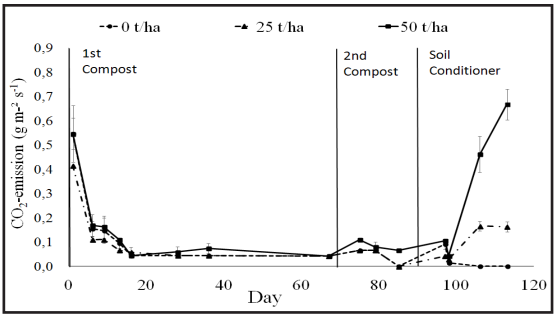

Figure 1. CO_2 emissions under 0 mg / L irrigation with different compost doses

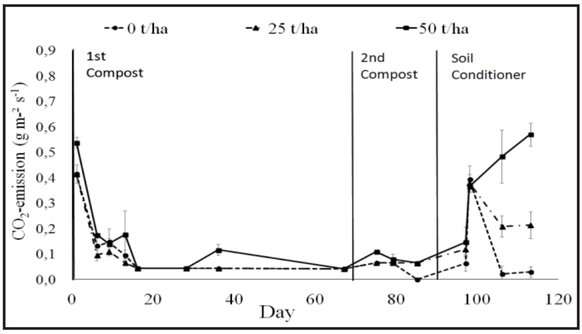

Figure 2. CO_2 emissions under 600 mg / L irrigation with different compost doses

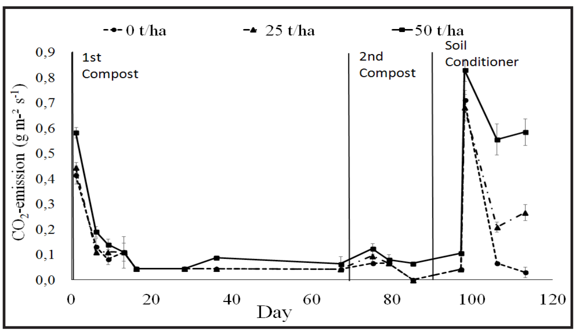

Figure 3. CO_2 emissions under 1800 mg / L irrigation with different compost doses

However, in sodic soils, lime is not suitable for reclamation. Limestone can be only used when acidifying amendment is applied prior to lime application. A common amendment procedure is application of gypsum ($CaSO_4 \cdot H_2O$). Common acidifying procedure for the reclamation of sodic soils is sulphuric acid and elemental sulphur. It is critical to oxidize sulphuric acid by soil microorganisms, and a lag time is several weeks to months before leaching begins. In general, those reactions take place in soils, which could lead emission of CO_2 from soil by chemical reaction (Abrol et al, 1988; Bohn et al., 2001).

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Thus, it can predict that sulphur in soil conditioner reacted with water and elements in well water such as sodium. Brinck and Frost (2009) also indicate that Ca can be mobilized through the addition of H_2SO_4. Gypsum reduces deterioration of clay-rich soil structure and improves infiltration rates. Under high Na and HCO_3^- concentrations, elemental S application converts some of HCO_3^- to CO_2 and reduces the precipitation of $CaCO_3$ and suppresses SAR.

The second spike on 116 days was led by the compost level. Although there were enough compost applied before, soil conditioner was the inducing reason on second spike. It is predicted that composition of compost or total elements were modified after addition of soil conditioner. It could happen because of two possible reasons, either leaching of excess salts or addition of nitrogen causing lower C/N ratio.

In some cases, glucose addition promotes microbial growth, and nitrogen or phosphorus increased at even higher ratio, while carbon addition does not affect respiration (Aldén et al., 2001). Liming has the potential to decrease C mineralization of SOM and plant residues, but mineral N has a positive effect on increasing CO_2 derived from organic matter. However, N effect was cancelled out if lime and N were applied simultaneously (Wachendorf, 2015).

In terms of salt concentration, salinity did not necessary correlate with CO_2 flux in this experiment. Yan and Marschner (2013) also found a similar result that soil respiration rate was highest in the low-salinity treatments and lowest in the mid salinity treatments, while the soil microbial biomass was highest in the high salinity treatments and lowest in the low-salinity treatments. This was attributed to increased substrate availability with high salt concentrations through either increased dispersion of soil aggregates or dissolution or hydrolysis of soil organic matter, which cancels the stresses on the microbial population from high salt concentrations.

Other studies focus respiration from the point of carbon-use efficiency (CUE). CUE is defined as a ratio of growth over C uptake. Riggs and Hobbie (2016) conducted seven-year of N addition, decomposition rate and respiration of SOM were both measured with decline trends. Additional nitrogen addition decreases CUE due to decreased oxidative enzyme activity. However, the mechanism remains uncertain. According to Manzoni et al. (2012), CUE of soil microbial communities increased as the C/N ratio of the soil or decomposing substrate decreased.

Conclusions

There were no significance of compost and salt on the microbiological activity of the soil till addition of a soil conditioner rich N, S, and Ca. After this addition, there was a chemical reaction, and followed bacterial reaction. Thus, there was more impact of SOM than salt in this experiment. Our results indicate that compost has played a role to suppress salt stress by increasing C/N and essential nutrients. Even though the addition of salt may not have been enough load to be stressed or not enough sufficient time compared to under practical situations where salinity develops to higher degrees, this experiment indicates the situation of starting point of salt-affected soils.

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